

An Approach Towards Application of Semiconductor Electronics Converters in Autonomous DFIM Based Wind Energy Generation System: A Review

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Abstract- This paper gives an approach towards the application of different semiconductor electronics converters in area of autonomous DFIM based wind energy generation system. For the operation of autonomous DFIM based wind energy system different control techniques are used which depends on the actual position and speed of rotor. Various control methods are given as stator flux oriented control methods; direct voltage control methods and MRAS observer based methods. These methods are usually applicable in autonomous DFIM based variable speed wind energy generation system.

Keywords Autonomous DFIM (Doubly Fed Induction Machine), semiconductor electronics converter, voltage source inverter, wind energy system.

1. Introduction

From the last 2-3 decades, economic atmosphere of the whole world depends on the renewable energy sources. Wind energy is a clean and eco-friendly renewable energy resource, which reduces dependency from fossil fuels. Wind energy system plays a very significant role to become more reliable renewable energy source across all over the world. The demand of wind energy increases gradually. At the end of 2020; it is expected that demand of wind power may be reaches up to 75 GW [1]. In fixed wind speed systems squirrel-cage induction generators are used, which is directly connected with grid system [4] as in case of variable wind speed [2]-[18]. This review paper focused on actual position of the rotor and speed sensorless control method operation in autonomous DFIM based wind energy generation system

[19]-[37]. In such system to control the variable-speed operation direct voltage control methods [37]-[55]; stator flux oriented control methods [72]-[74]; and MRAS observer based methods [90]-[103] are used. For higher wind velocity, active pitch angle control method is used to overcome the generated aerodynamic power by changing the actual position of rotor blades through suitable angle from wind direction. To resolve the problem of high wind speed operation, wind turbines are fabricated using power control scheme. Primary techniques used for power control [21] in wind turbines systems are: - a) Pitch controlled b) Stall controlled c) Active stall controlled d) Yaw controlled.

In case of pitch controlled wind turbine system an electronic regulator is used for continuous observation of wind turbine output power. An actuating signal is generated

when the output power cross the threshold limit and send this actuating signal to the blade pitch mechanism for immediately pitching (turning) the rotor blades marginally out of the wind. On the other hand when the output power again within the threshold limit due to moderate or low wind speed, the blade pitch mechanism again turning or pitching back the turbine blades in the direction of wind. Thus turbine blades are capable enough to move or turn pitch with reference to their longitudinal axis. Normally at a time, a small degree of turn will be given to the turbine for moving rotor blades in case of pitch controlled wind turbines. In stall controlled based wind turbines; the rotor blades bolted on head of the hub with a fixed angle. In stall controlled wind energy system, moving towards its longitudinal axis, the rotor blades distort fairly. The output power is controlled through the design of rotor blades. In case of 1 MW & above rated wind energy systems, active stall control is preferred more. It is quite similar as pitch controlled mechanism, having pitchable blades operate through either hydraulics or electric stepper motors. In case of active stall control, the output power is more precise as obtained in case of passive stall. The machine can also be run near to rated power for every permissible wind speeds. In case of tiny wind turbines (1 kW or less), Yaw control technique is used [13]-[22].Section II shows the basics of wind energy generation systems and various semiconductor electronics converters used in variable wind speed operation are discussed here. Section III provides brief review about autonomous DFIM based wind energy generation system, and Section IV contain control techniques used in autonomous DFIM based wind energy generation system. Section V consists of complete conclusions of the above.

2. Basics of Wind Energy Generation System

Fundamental components of a wind turbine system are presented in Fig. 1. It consists of wind turbine, gearbox, generator, semiconductor electronics converter, coupling transformer for grid connection. Wind is main source of power for wind turbines operation; depends on the structure of the rotating blades which converts wind power into revolving mechanical power [9].

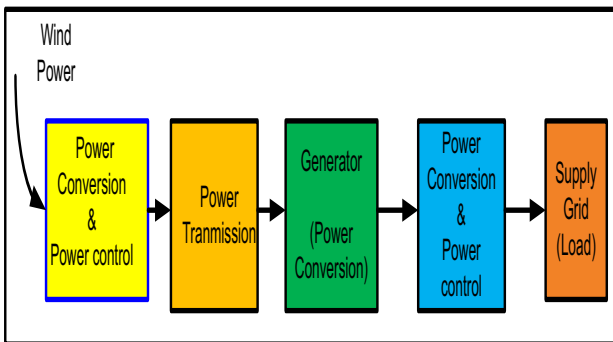


Fig.1. Basic elements of a Wind Energy Generation System

As per the revolving speed, it is categories as: - variable speed wind energy system and fixed speed wind energy system. Variable speed DFIM based wind energy generation

system having a wound rotor induction generator & semiconductor electronics converter on the rotor side. Its operation can be presented in to four quadrant systems and having capability of supplying and consuming active and reactive power from the grid. A more detailed about the operating modes of the DFIM based wind energy system is shown in Figure 2.

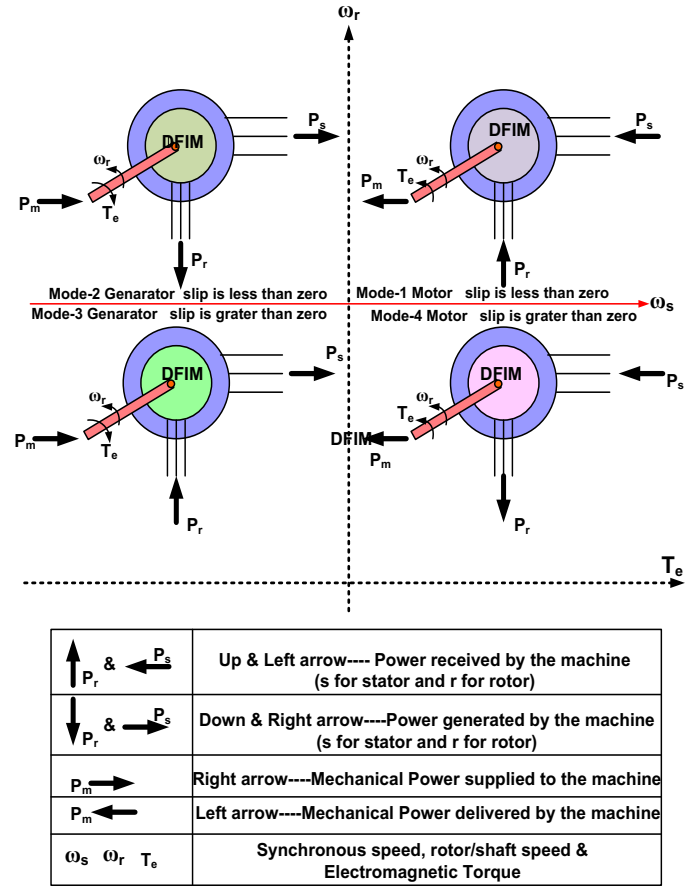


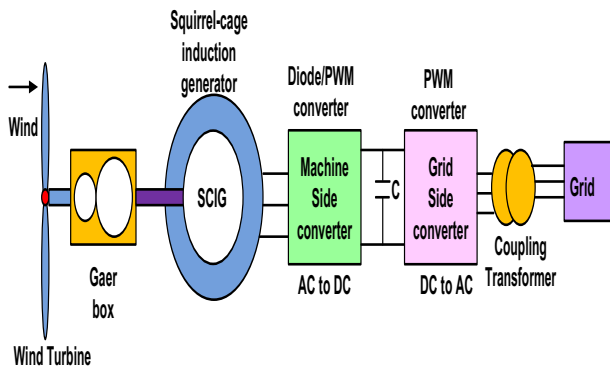
Fig. 2. Different possible operating modes of DFIM system

It has two operating modes such as Sub-synchronous; Super-synchronous. This mode of operation depends on the angular speed of rotor with respect to synchronous speed. Fully controlled semiconductor electronics converters are used to control rotor current injection in case of sub and super synchronous modes. In super synchronous mode, angular speed of rotor is slower than synchronous speed. Real power is drawn from the stator/grid (or any other external source) and delivered to the rotor via semiconductor electronics converter where as in case of sub synchronous mode; rotor angular speed is greater than synchronous speed. Power is generated in rotor (in addition to power generated in the stator) and delivered to the grid/load via semiconductor electronics converter. In such type of system gear boxes are used to maintain lower shaft speed to higher speed; acceptable in case of DFIM based wind energy generation system. Variable speed wind energy system can be

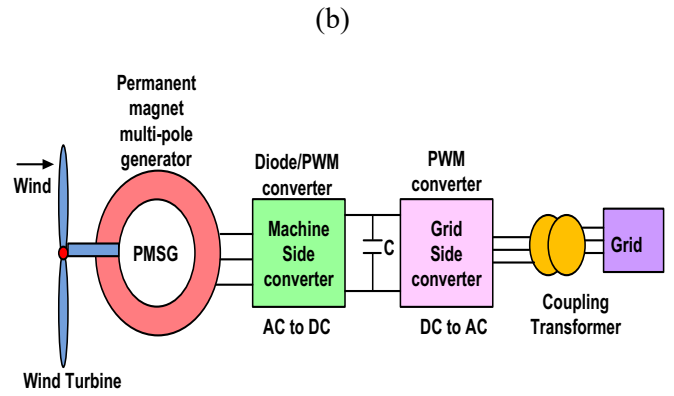
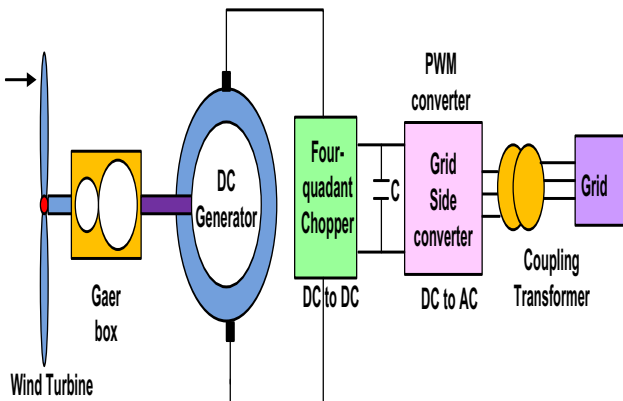
categorized on behalf of power rating of the semiconductor electronics converters. In power generation the role of power rating of converters are very important. In wind energy generation system full-scale and partial-scale semiconductor electronics converters are used for power generation.

2.1. Variable speed wind energy system using full-scale or full rated semiconductor electronics converter

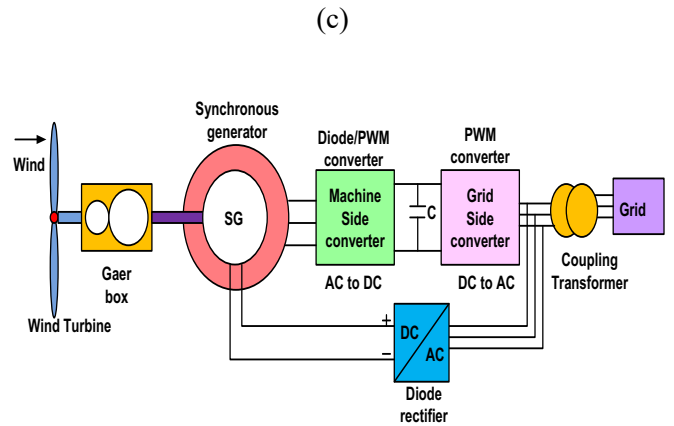
The concept of variable wind speed energy system with full-scale semiconductor electronics converters are used in synchronous generators and squirrel cage induction generator system. A full rated semiconductor electronics converter is connected in between generator and grid. It is connected in back-to-back position in between two voltage source converter with a common capacitive dc link. This system is used to control the generated active and reactive power from the grid in bidirectional nature [57]-[60]. In the synchronous generator at the generator end, bridge rectifier may be used but the overall system in not completely controlled i.e. to achieve the maximum power point tracking, generator speed is not properly regulate as per wind speed [25]. When generator is separated from the grid, a large scope of frequency/speed is feasible for optimal operation. Enhancing of the dynamic response of the system and separately control of active and reactive power can be done through grid-side converter. Fig. 3 shows different feasible design of variable speed wind energy generation system using full-scale semiconductor electronics converters [27].



(a)

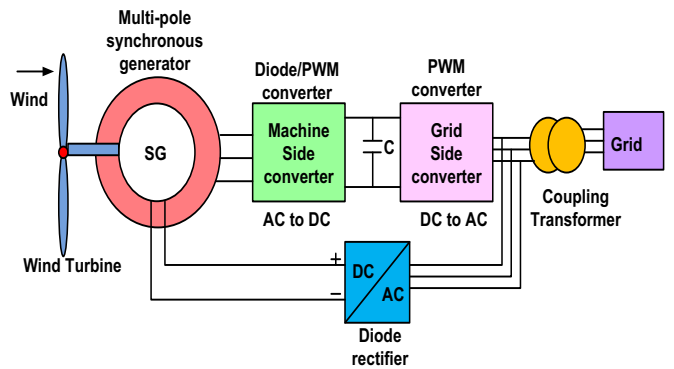


(b)



(c)

(d)



(e)

Fig. 3. Schemes for variable-speed full-scale semiconductor electronics converter based wind energy generation system (a) by using squirrel cage induction generator (b) by using dc generator (c) by using synchronous generator (d) by using multi-pole synchronous generator (e) by using permanent magnet multi-pole generator

The various possible configurations depend on the variable wind speed based wind energy generation system using squirrel cage induction generator is given in Fig. 3a. In this configuration stator is connected through grid with back-to-back connected 3-level voltage source semiconductor electronic bridge converters [57]. The power rating of stator defines the actual size of power converter which is capable to covert generated wind power into stator power. Designing of gearboxes are done in such a manner that the maximal speed of rotor corresponds to estimate speed of the generator. The

main advantage of variable speed configuration is to better utilization of available wind power and to reduce the necessity of capacitor bank. The available capacitor banks used to draw reactive power from grid [54]. Major drawback of this configuration is higher cost and more losses with full scale converter. The overall performance of system (gearbox, induction generator and converter) may be reduced. In this configuration, shown in Fig. 3b instead of classically used alternating current based machine, permanent magnet based dc generator is used for providing conversion of energy using wind energy generation system. Due to cause of simple design, dc machine has been selected for operation, but ratings and limited speed operation are the main drawback of this configuration. Moreover dc machines have well known demerits in reference to power generation.

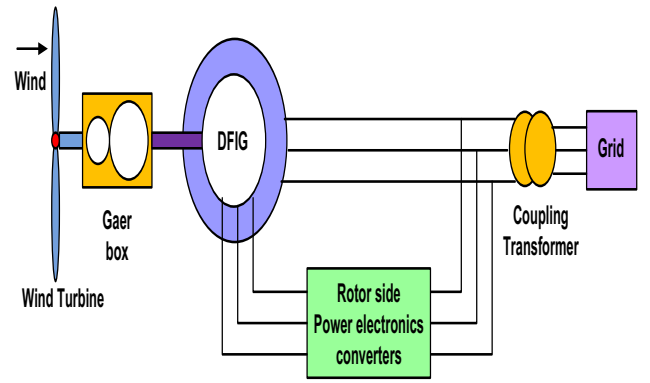
The grid connected variable speed Permanent Magnet Synchronous Generator (PMSG) based wind energy system is given in Fig. 3c. Here PMSG may be used as a generator because of smaller in size. Due to cause of self excitation property, PMSG play a significant role in wind energy technology, which allows an operation at high power factor and higher efficiency. Additionally, PMSG has shown inherent economic and technical advantages, such as in the absence of field losses, PMSG have better thermal characteristics, higher reliability, large power to weight ratio and better dynamic stability [51]. Nevertheless, PMSG have some drawbacks such as: higher material cost; difficulties in handling during construction, demagnetization at high temperature.

In general for low power application PMSG is used but in larger systems synchronous generator may also be used. The synchronous generator which is excited electrically, designed through a rotor carrying dc excitation field windings. The 3-phase winding of stator is similar to induction machine which does not depend on type of poles of rotor. In case of low speed synchronous generator system, salient pole based field system are more reliable for wind energy generation system. A grid connection scheme of electrically excited synchronous generator based wind energy system is indicated in Fig. 3d. In this system, gear box can be removed through multi-pole machine as shown in Fig. 3e. They all are applicable for full scale or fully estimated semiconductor electronics converters, which minimize the manufacturing cast and overall performance of the system.

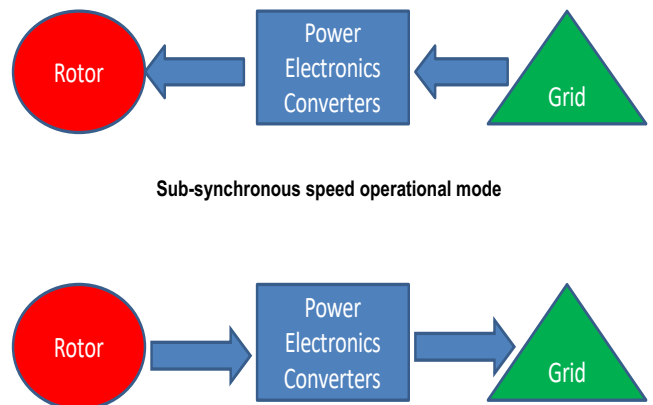
2.2. Variable speed wind energy system using partial-scale or partial rated semiconductor electronics converter

DFIM is applicable for variable speed wind turbine systems which having a wound rotor induction generator and semiconductor electronics converter connected at rotor side represented in Fig. 4a. It operates into four different quadrant systems, which are used for supply and absorbing the active and reactive power connected through grid. Depending on the rotor speed in may be operated into two different modes known as sub-synchronous and super-synchronous [26]-[28]. These operating modes dependent on angular speed of rotor which depends on synchronous speed. Fully controlled semiconductor electronics converters are used for controlling

of the rotor current injection in sub-synchronous and super-synchronous mode. In sub-synchronous mode, rotor speed is less than synchronous speed thus real power can be drawn from the stator/grid (or any other external source) and delivered to the rotor via semiconductor electronics converters as shown in Fig. 4b. In case of super-synchronous mode of operation, the rotor speed is greater than the synchronous speed hence power generated in rotor (in addition to power generated in the stator) and supply to the grid/load via semiconductor electronics converters given in Fig. 4b. DFIM based wind energy generation system having number of gear box are used to increase the rotational speed of wind turbine shaft to generate electrical power for DFIM operation.



(a)



Super-synchronous speed operational mode,

(b)

Fig. 4. (a) Scheme of a variable speed concept with DFIM based wind energy generation system (b) Power flow direction under the sub-synchronous and super-synchronous modes

DFIM having a wide operational speed range which actually depend on the actual rating of semiconductor electronics converter. In this mode of operation the allowable speed ranges exist from +30% to -30% near to synchronous speed [21]. The power generation capacity of semiconductor electronics converter is up to 25–30% depending on the converter rating, which is very essential from an economic

magnitude and angle) into three phase quantities. On comparing the reference rotor currents with measured one, error signals are generated which generates the PWM signal for rotor-side semiconductor electronics converter. This DVC technique ensures that the constant stator voltage vector magnitude and its position angle are used to give the constant voltage magnitude, frequency and controlled phase voltage.

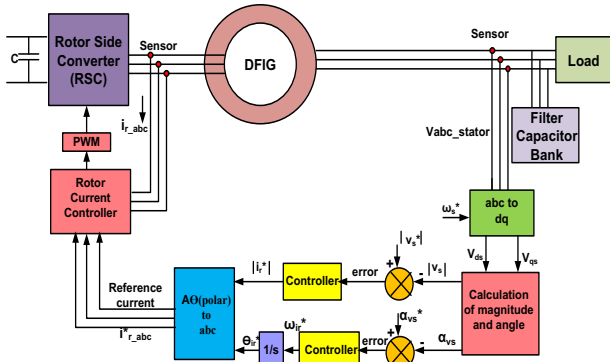
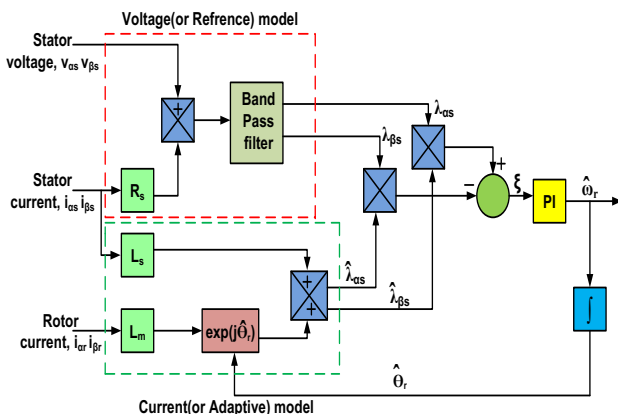


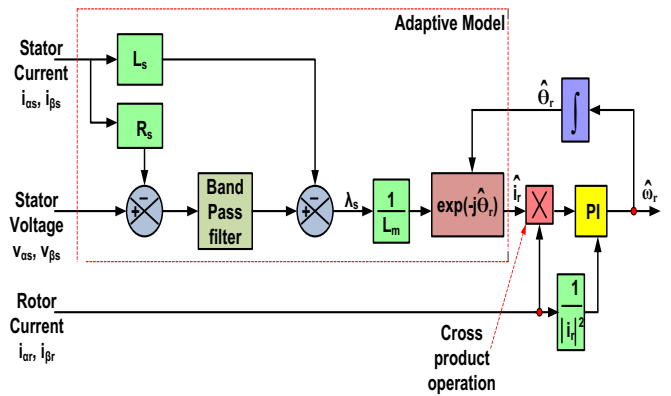
Fig. 7. Direct voltage control method

4.3 MRAS Observer based control technique

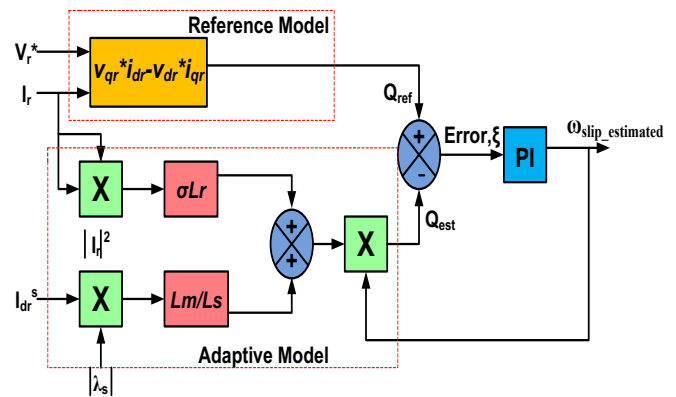
In case of cage induction machines the Model Reference Adaptive System (MRAS) method is recognized for sensorless control. Few data required for the application of MRAS observers in case of sensorless control of autonomous DFIM based wind energy generation system. Open loop types of observer are suitable for estimation of error uncertainties present in the model. Whereas closed loop observers are more efficient in case of steady state and transient type of control system [68]. For estimation of rotational speed and rotor position of DFIM, MRAS speed observer is used. Different types of MRAS observers are Stator-flux-based MRAS observer, Stator current based MRAS observer, Rotor current based MRAS observer, Rotor flux based MRAS Observer, Reactive power based MRAS Observer. In Rotor flux based sensorless control; rotor flux is obtained by the integration of the rotor back-electromotive force. When it operates near to synchronous speed, rotor excitation occurs at low frequency thus its performance reduces due to cause of integration problem available in the system.



(a)



(b)



(c)

Fig. 8. (a) Stator-flux-based MRAS observer (b) Rotor current based MRAS observer (c) Reactive power based MRAS Observer (Q-MRAS)

In stator flux based MRAS observer, flux obtained from the voltage model used as reference flux. By adjusting the estimated rotational speed, generated error in between reference flux and estimated flux is given to PI controller which provides the estimated rotational speed. In case of rotor current based MRAS observer, rotor speed and position are estimated using the rotor current. This current can be obtained from direct measurements through transducers. This current is compared with an estimated rotor current obtained from the stator voltage. PI controllers are used for processing the error which gives the estimated speed for correcting the estimation of the rotor position and speed. This primary model for reactive power based MRAS observer having a reference model which computes the instantaneous rotor side reactive power. An adaptive model is used to give the steady state reactive power. Generated error is processed through a PI controller and output signal provides estimated slip speed. This estimated slip speed is used to tune the adaptive model such that error minimized to be zero. The Q-MRAS is suitable for speed catching operation, but it gives incorrect

results of speed estimation when the direct-component of rotor current is varied.

5. Conclusion

A review on the application of semiconductor electronics converters in autonomous DFIM based wind energy generation system has been presented and discussed here. Different generators and semiconductor electronics converters used in variable speed wind energy generation systems are also reviewed and discussed in brief to give more insight about the concerned topic. Variable speed DFIM based wind energy generation system has shown dominance in the wind energy market largely because of the fractional power rating (25%-30%) of semiconductor electronics converter system. Autonomous/stand-alone DFIM based wind energy generation system has been presented and discussed where the control of voltage and frequency at stator terminal is the main subject of concern. Using the proposed control technique, the stator voltage and frequency are balanced and constant at their reference values. Different techniques to control the autonomous DFIM based wind energy generation system has been summarized and discussed. The proposed techniques may be valid for both linear and non-linear loads. Future work will concern the laboratory tests of the proposed techniques in the paper.

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